half of the star turned towards us during that time ; and during an indefinitely short exposure might be said to represent the condition of the surface visible to us as it was during a certain minute time interval when the waves set out from that surface. [Neglecting for the moment the modification of this statement which the curvature of the star's surface would render necessary owing to the fact that the light which proceeded from the extreme outer edge would have a longer distance to travel than that in the centre by a little more than the radius of the star, and therefore its arrival at the instrument might be later than that from the central portion.]

But the broadening of this line into a surface by making a slight difference between the rate of the clock-work and the angular motion of the earth, would represent this same elongated surface of the star at different times. In other words the one axis would represent different parts of the star at the same instant of time, and the other axis would represent the same region (the hemisphere visible to us) at different periods of time.

If the movements of the atmosphere of the star observed were as rapid and extensive as those of our own sun, the consequence would be that we would have a succession of different conditions of the star's atmosphere placed in close juxtaposition, the whole series representing all the changes that had occurred in the star's photosphere during the interval of exposure. On this account it would seem that this method was not adapted to do more than give the resulting average of these changes on a sensitive plate of measurable breadth and would not permit the condition of the photosphere at any one instant of time to be studied.

It would be interesting to know what effect a similar procedure on the disc of the sun would show, by juxtaposing a large number of instantaneous photographs of the disc as different parts of the latter were successively brought over the slit of the spectroscope.

Notes on the Surface Geology of South-west Virginia. By John J. Stevenson.

(*Read before the American Philosophical Society, May 20, 1887.*)

New river, rising in North Carolina, flows across the Archæan area of Virginia, and enters the "Great Valley" of that State in Wythe county. It flows through Wythe and Pulaski counties, separates the latter from Montgomery, and flows through Giles county into West Virginia on its way to the Ohio river at Point Pleasant. It drains the counties named, with the addition of Bland. The most important forks of the Holston river flow through Smyth and Washington counties of Virginia into Tennessee ; while the Clinch river rising in Tazewell county of Virginia flows through Russell and Scott counties and drains much of Wise. It is joined in Tennessee by Powell river, which drains Lee county and part of Wise.

The Clinch and Holston unite to form the Tennessee, through which their waters reach the Ohio at Paducah.

The effects of erosion in Bland county are seen in the removal of limestone and shales so as to throw the harder rocks into relief as mountains; to form narrow valleys in limestones near the present lines of faulting, and to scoop out a basin in Devonian and Upper Silurian shales. Within Giles county, New river flows on Knox (Calciferous) limestone, and the later rocks have been eroded from a considerable space on both sides of the stream. The conditions became approximately the same throughout this area after the removal of the Devonian and Upper Silurian, and good illustrations of certain types of erosion are afforded here as well as further southward along New river.

Remnants of two planes of erosion, one 225 (1810 feet above tide) feet and the other 115 (about 1670 feet above tide) feet above New river at Snidow's ferry, were seen in Giles county on the road from the county-seat to that ferry, which is opposite the mouth of Big Stony creek, where the altitude of the water surface is about 1555 feet above tide. The upper plane originally extended far into the recess between Pearis and Sugar run mountains;* and even now it can be recognized easily in the many hills, whose leveled tops have almost the same altitude. The second plane is more distinct, being better preserved than the other, and having a larger area. Still lower benches, river terraces, were seen, but they do not exist on the road followed by the writer, and no measurements of their height could be obtained.

The deposit on the higher planes is sand and clay, carrying vast numbers of transported polished fragments, most of which are barely three inches in diameter, though some were seen upwards of ten inches. For the most part, these pebbles are of local origin, or, at least, they came from the confines of the "Great Valley," for the sandstones predominate; but there are not wanting pebbles of glassy and milky quartz, seldom more than four inches in diameter, which must have come from the Blue Ridge, not less than seventy miles away by the nearest water-line. And these are found on the highest bench at nearly three miles from the river's present channel way.

A fine plane of erosion is well preserved on both sides of New river south from Little Walker mountain in Pulaski and Montgomery counties. Its summit is shown on the west side of the river near Belspring station, with an altitude of not far from 1775 feet above tide, the station being 1766 feet A. T., while a higher plane is reached along the New River R. R. on this side of the river at the summit cut, two and a half miles from New River station, and about 1925 feet above tide, the track in the cut being

* For explanation of the relations of the mountains and of most of the localities referred to in this paper, the reader is referred to memoirs on Southwestern Virginia, published by the writer in Proc. Amer. Phil. Soc., as follows: Vol. XIX, pp. 88, 219, 498; XXII, p. 114, and XXIV, p. 61. The faults are described summarily in a paper in the Amer. Journ. of Science for April, 1887.

1914 feet. This bench extends eastward from New river for more than eight miles between Little Walker and Price mountains, and it is probably the same with the fine terrace shown above the railroad bridge over New river. It is distinct on the west side at four miles from the river on the railroad; and it appears to be the same with the plain seen nearly six miles further west on the road leading across Pulaski county from Dublin to Pearisburg; but the barometric readings on that road are not wholly satisfactory.

The deposit on these benches is of clay and sand, containing pebbles of varying size, most of them, as before, of local origin, but not a few of them have come from the Blue Ridge. The upper bench is deeply trenched here and there by narrow valleys in which rock exposures occur; elsewhere such exposures are rare, as the detrital cover is from five to thirty feet thick. River terraces, apparently unbroken and almost as perfect as those shown in theoretical diagrams were seen in the "Horseshoe bend" bottom, but they could not be reached for measurement.

Erosion planes are equally well marked along New river within Wythe county for some distance above and below the Wythe lead and zinc mines. The lead company has sunk a shaft at about half a mile south from New river, beginning at the topmost part of the bench, which, according to the barometer, is 310 feet above the river at Thorn's ferry opposite the company's offices, or 2260 feet above tide. The surface is covered with loose boulders, mostly three inches or less, though some are fully eight inches. The deposit, as found in the shaft, is nearly fifty feet thick, and the bench is of great extent on this southerly side of the river. Crossing to the other side and taking the road over Lick mountain to Wytheville, one soon comes to a bench, 120 feet by barometer above the river or 2070 feet above tide. This was not recognized at the lead mines on the southerly side of the river, but on this side it is distinct almost from Jackson's ferry to the Wytheville road, on which it is reached at three miles from New river. The higher bench is reached by the Wytheville road at six miles from the river, and, according to the barometer, is 320 feet above low water at Thorn's ferry or 2270 feet above tide. It carries a thick coat of debris loaded with pebbles.

The tributary streams of New river are terraced. A fine bench was seen on Wolf creek in Giles county at a mile or so from the river. It is sixty-five feet above the stream and carries a thick deposit, which is rich in rolled stones. The upper terrace of Reed creek below Wytheville was not measured, but it is fully 150 feet above the stream. It shows huge boulders of Potsdam sandstone resting on the Knox limestone, though a broad and deep ravine separates their resting place from Lick mountain, whence they came. An erosion plane, similar to that seen in Pulaski county, was observed north from Wytheville within the New river area. Its superficial deposit of sand, often carrying many pebbles, is so thick as to conceal the bedded rocks for long distances.

Great planes of erosion are shown in all parts of the "Valley" from the Tennessee line to the eastern side of Montgomery county; no doubt they are continuous thence into Pennsylvania, where such planes are sufficiently distinct. At all localities they illustrate effects of erosion during a long period in which the channel-ways of the main streams are not deepening materially.

By some means the erosive or channel-deepening power of the New river has been greatly increased since the erosion of the upper planes was completed; for the river has excavated a gorge 255 to 300 feet deep with the hills abrupt on one or both sides for considerable distances; while erosion extends at best to but a little way from the river. The tributary streams flow for the most part in comparatively narrow valleys, even where the conditions appear to be such as to favor extended erosion. Meanwhile the destruction of the elevated planes has gone on irregularly; the upper bench south from Walker mountain has suffered little in Montgomery county except near the river. But that in Giles county has been eaten away and another, widely extended, has been formed at a lower horizon; and there appears to be nothing south from Walker mountain to compare in extent with the lower plain north from that mountain.

While the erosion of the "Great Valley" and of the region drained by New river appears easily referable to a simple plan, the conditions in the limestone area of Tazewell, Russell and Scott counties, drained by Clinch river, are not so clear. Benches exist, but they are not so obvious as are those in the valley, they do not always carry a deposit loaded with pebbles and they seem rarely to have great extent. One gravel deposit was found on the line between Russell and Scott within a mile of Clinch river and at 640 feet above that river at Osborn's ford, making its height above tide not far from 1920 feet. The pebbles are rarely larger than a hen's egg, and are mostly quartz; comparatively few could have been derived from the region now drained by the Clinch, and most of them must have come from the Blue Ridge or further at the south.

The Clinch and North Holston are as handsomely terraced as the New river and its tributaries. The "bottom" of Clinch river appears to maintain a uniform height of about fifteen feet above low water; a fine terrace is shown near Osborn's ford at ninety-five feet above the river or 1375 feet above tide, and it is present on both sides of the river at a little way above the ford. A higher bench is shown on the southerly side, but its height could not be ascertained. Near Nash's ford in Russell county, three terraces are crossed as one descends to Clinch from the south. These are about 155, 40 and 15 feet above low water at the ford. The highest reaches far back from the river and its height above tide is not far from 1700 feet. A fine terrace was seen on the north fork of Holston below the mouth of Laurel creek in Smyth county, where the top of the deposit is between eighty-five and ninety feet above the river or at not far from 1625 feet above tide. The deposit on these river terraces consists of sand and clay carrying abundance of boulder, all apparently of local origin.

In some portions of South-west Virginia, notably in the region embracing much of North-west Tazewell county, Virginia, and of Mercer and Summers counties of West Virginia, which is known as "Flat Top," there are high benches or fragmentary plains which are of considerable extent, but do not appear to carry many water-worn stones in their thin cover. They are very like the higher benches observed by the writer* in South-west Pennsylvania, and very possibly they are due to the same causes.

But what these causes were is still an open question. The most natural explanation is that which regards them as erosion planes, such as were termed "base levels of erosion" by Major Powell. But in discussing these benches as they occur in Pennsylvania and adjacent States, the writer showed that as they line valleys and form irregular rings about isolated hills, they are merely incidental modifications of a topography due to prior and long continued erosion ; and that they are too well preserved to be regarded as fragments of great erosion planes. More than this. The deposit on these benches is marked by the absence of water-worn and rounded fragments ; the absence of such fragments cannot be accounted for by the supposition that they have been broken up by exposure, for the greater part of the deposit has been protected from atmospheric agencies until exposed by the plough or in excavations for roads. The Coal Measures of Western Pennsylvania contain sandstones, whose fragments should resist disintegration equally with the Medina and Potsdam pebbles of South-west Virginia ; while in Bedford county of the former State, where high benches are as conspicuous as in the Coal Measures counties further west, the Chemung conglomerates and the Medina sandstones are present and the stream beds are loaded with their fragments ; yet no rounded pebbles were seen on the benches.

The absence of these boulders militates against any application of the base-level process, as generally understood, and equally against the supposition suggested by the writer, that the benches were produced by shore erosion between tides. The problem of their origin is not simplified by denying their existence, for, unfortunately, the benches are "here to stay." A ride along the National road in Pennsylvania, from Uniontown in Fayette county to Washington in Washington county, enables one to secure a key to the whole succession.

Returning to Virginia. That the great erosion has occurred since the faulting took place is sufficiently shown by the contrast between the upthrow and downthrow sides of the faults ; for on one side is seen the highest portion of the Lower Carboniferous, while on the other are the lowest beds of the Knox limestones. It may be that the main streams antedated the faults and possibly the folds. The course of New river, which rises far beyond the axis of the Blue Ridge crosses at least six great faults as well as all the folds, great and small, from the Blue Ridge to the Ohio river, suggests that it may be following in a general way the original direction.

*Proc. Amer. Phil. Soc., Vol. XVIII, Aug. 15th, 1879.

But there have been great changes in the water-ways. The fragmentary deposit on the line between Russell and Scott counties, carrying quartz pebbles at 640 feet above Clinch river, tells the story of one great change, for nothing along the upper Clinch could furnish the material for this deposit, of which so little remains. The deep erosion near the North fork of Holston river, from Saltville in Smyth county eastward for sixteen miles, cannot be referred to any present drainage system ; its bottom is more than 600 feet below the present bed of the river and the excavation has been filled with a deposit of gypsum and rock salt. This was digged out after the faulting, for the excavation crosses and re-crosses the Saltville fault.*

It is sufficiently clear that the courses of many of the present streams are due in no small degree to the geological structure. The fans formed by the Clinch and Holston with their tributaries show a co-incidence with the general course of the rocks and faults which cannot be merely fortuitous. Tributaries to New river in Bland and Giles counties flow irregularly with the strike of the beds ; between outcrops of sandstone they follow the more readily yielding rocks, so that they are often brought near to the fault lines ; and many streams belonging to the other systems do the same. But in the broad limestone areas, some other cause has determined the direction, for not a few streams exist there whose courses appear to bear no relation to the geological structure. No especial weakness now exists in the immediate vicinity of the faults, for the streams flow with utter indifference to them. New river crosses all of the faults. Big Walker creek and the North fork of Holston flow back and forth over the Saltville fault, and the latter at times wanders to a distance of two or three miles, apparently without reference to the character of the rocks. Clinch river coquettes in the same way with the Clinch faults and eventually deserts them to cross the limestone area in Scott county and to cut the Copper creek fault at ten miles toward the south-east. The North fork of Clinch crosses two faults and many of the smaller streams flow directly across one or more.

It is altogether probable that the present lines of the faults are very far, in some cases at least, from the original lines. The lateral thrust in more than one case must have been enough to push the upthrown rocks to a considerable distance over upon the downthrown series ; so that the areas of weak or crushed or much distorted rocks lay north or north-west from the lines as now observed. The crushed portions have been removed by erosion and the streams have changed their channel-ways as the erosion advanced. It is difficult, therefore, to determine much respecting the former drainage ways.

The thickness of rock removed by erosion in this region, though not equal to that removed from Western Colorado and adjacent parts of Utah, is still sufficient to challenge respect. There is no room for doubting that the Coal Measures reached at one time beyond the "Valley" to the Blue

*See Proc. Amer. Phil. Soc., Vol. XXII, p. 154 *et seq.*

Ridge, for those rocks are just missed on the northerly side of the Draper Mountain fault, at twelve miles from the Blue Ridge. Even now the Coal Measures must be caught on some of the Washington county hills beyond the Saltville fault. The Lower Potsdam is brought up under the Lick Mountain anticlinal at not more than four miles from the line of the Lower Carboniferous in the Draper Mountain area. The whole of the Palæozoic column, then, or not less than 22,000 feet, has been removed from the westerly side of the Blue Ridge in South-western Virginia; while in the "Valley" and on the upthrow side of the faults the thickness of removed rocks is from say 18,000 feet in Lick mountain to 12,000 feet or more along the faults. Additional proofs of this enormous erosion are found in the occurrence of Lower Silurian valleys separated by ridges carrying small areas of the Coal Measures.

This enormous erosion occurs only on the upthrow side of the faults; so that on the downthrow side one may find even the Coal Measures, while the lower beds of the Calciferous may be on the other. So, 15,000 feet or more may have been removed from one side, while on the other, the whole loss may not exceed 3000 or 4000 feet. This great contrast between the two sides seems to suggest that the lateral thrust was enough in every case to *push the upthrown beds far over on the downthrown*, so that there could be no erosion of the latter until after removal of the former.

Of course, there are perplexing problems here; they usually abound. One is suggested by the successive increase in height of the erosion planes as one ascends New river. Thus the highest south from East River mountain is at 1810 feet above tide; that south from Big Walker mountain is at about 1925 feet; while that south from Draper and Lick mountains is at about 2270 feet. These benches were all made during a long period when the river in each area had practically ceased to deepen its channel-way. It may be that the Medina sandstone of Draper mountain, the Chemung conglomerate and Medina sandstone of the Walker mountains and the Medina sandstone of the East River mountains may have proved sufficiently hard to resist erosion for a long time. However that may be, corrasion advanced regularly after it began, for the first bench below is reached at 140 feet south from East River mountain, at 150 feet south from the Walker mountains, and at nearly 200 feet in the space between Lick mountain and the Blue Ridge.*

A long halt in corrasion occurred during the formation of the second bench; but thenceforward no important obstacle seems to have been encountered and the interruptions were only long enough to admit of forming narrow river terraces, which usually are found on but one side of the river.

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* For the elevations along New river, I am indebted to Mr. W. W. Coe, Chief Engineer of Norfolk and Western R. R.; and for those on the Clinch and Holston rivers to Mr. Oramel Barrett, Jr., of Abingdon, Virginia.